Comparisons of Measurements and Predictions of PM Concentrations and Emission Rates from a Wind Erosion Event

Paper #11020

K. Moore[1,2], M. Wojcik[1], C. Marchant[1], R. Martin[2], R. Pfeiffer[3], J. Prueger[3], J. Hatfield[3]

[1] Energy Dynamics Laboratory, Utah State University Research Foundation, North Logan, UT

[2] Dept. of Civil and Environmental Engineering, Utah State University, Logan, UT

[3] National Laboratory for Agriculture and the Environment, USDA ARS, Ames, IA

Abstract

Wind erosion can affect agricultural productivity, soil stability, and air quality. Regulatory standards for ambient levels of particulate matter (PM) with equivalent aerodynamic diameters ≤ 10 µm (PM_{10}) and ≤ 2.5 µm ($PM_{2.5}$) have been established in many countries in an effort to protect the health and welfare of their citizens. Wind erosion events may lead to high PM levels that exceed air quality standards and are health hazards. Quantifying suspended wind-blown dust emissions and resulting PM concentrations from wind erosion events are therefore, of significant interest.

A high wind event causing visible soil suspension occurred on May 20, 2008 in California's San Joaquin Valley. On this day, PM concentrations around a field with fine sandy loam soil were measured as part of an agricultural tillage PM emissions study. Point sensor PM instruments deployed were a vertical and horizontal array of optical particle counters (OPCs) and portable filter-based PM samplers. A remote sensing scanning Lidar (light detection and ranging) system with three wavelengths (1064 nm, 532 nm, and 355 nm) called Aglite was also sampling. The OPCs were used to calibrate the Lidar return signal to particle count and volume concentration. Mass concentration calibrations for both the OPCs and Lidar were calculated from OPC and filter-based PM data collected that day. The filter-based sampling was stopped upon completion of the tillage activity while the OPCs and Lidar continued to collect data during part of the wind erosion event. Emission rates (ERs) were calculated by a vertical flux method with OPC PM data, an inverse modeling technique using AERMOD with OPC PM data, and a mass balancing technique applied to upwind and downwind vertical Lidar scans.

PM values measured downwind of the field were consistently much higher than those measured upwind, showing significant suspension and vertical dispersion of soil particles from the field up to 9 m. Particle size distributions and PM levels were also consistently higher at 2 m than 9 m in both upwind and downwind locations, suggesting most particles in the wind-blown dust plumes stayed near the surface. All OPCs, especially those downwind, had high counts for particles > 1 µm relative to counts of particles < 1 µm in comparison with typical ambient atmosphere particle size distributions. The Lidar detected wind-blown dust plumes of varying size, location, and duration on the downwind field edge from 10 m to 50 m in elevation. ERs based on the vertical flux method were 3.9 µg/s-m² for $PM_{2.5}$, 174.2 µg/s-m² for PM_{10}, and 872.0 µg/s-m² for TSP; ERs from inverse modeling were 6.1 µg/s-m² for $PM_{2.5}$, 268.7 µg/s-m² for PM_{10}, and 1,488.9 µg/s-m² for TSP. These PM_{10} ERs are similar to other values in literature. The Lidar-based ERs were three orders of magnitude lower than those from the other two methods. A minimum measurement height of ~10 m due to safety concerns prevented the Lidar from adequately detecting plumes that are close to the ground, such as the wind erosion plumes seen on this day.

Introduction

- Wind erosion can damage crops, remove topsoil, and impact local, regional, and global air quality
- Understanding processes and emission rates (ERs) of such events are important
- EDL measured PM concentrations during part of a high wind event near Hanford, CA in May 2008 as part of a tillage PM emissions study
- PM levels and estimated ERs are shown here

Methodology

- Designed as a tillage PM emissions study, not a wind erosion emissions study
- Rectangular field with a 280 m downwind fetch across the field
- Soil was fine sandy loam, saline-alkali
  - 62% sand, 29% silt, 9% clay by the Hygrometer Method
- Initial surface conditions (see Fig. 1A): dry (3.3% average soil moisture), fully disturbed with ridges made immediately prior to high wind event
- Point Sensor PM Measurements
  - Met One Instruments OPC (0.3 ≤ d_{opt} ≤ ~25 µm in 8 size bins)
  - Airmetrics MiniVol PM Samplers configured for $PM_{2.5}$, PM_{10}, TSP
  - Arrayed horizontally and vertically upwind and downwind of field (See Fig. 1B)
  - OPC calibrated to mass using MCF, a relationship between MiniVol PM_k and OPC V_k
- Aglite Lidar (see Fig. 1C)
  - Nd:YAG micropulsed laser at 1064, 532, and 355 nm
  - Horizontal scans over field with vertical scans upwind and downwind
  - Aerosol PSD calibration using OPCs
  - Mass calibration using MCF
- Fig. 2 presents a sampling layout map
- Times of data collection: OPCs – 12:50 to 15:45, Lidar – 12:50 to 14:00

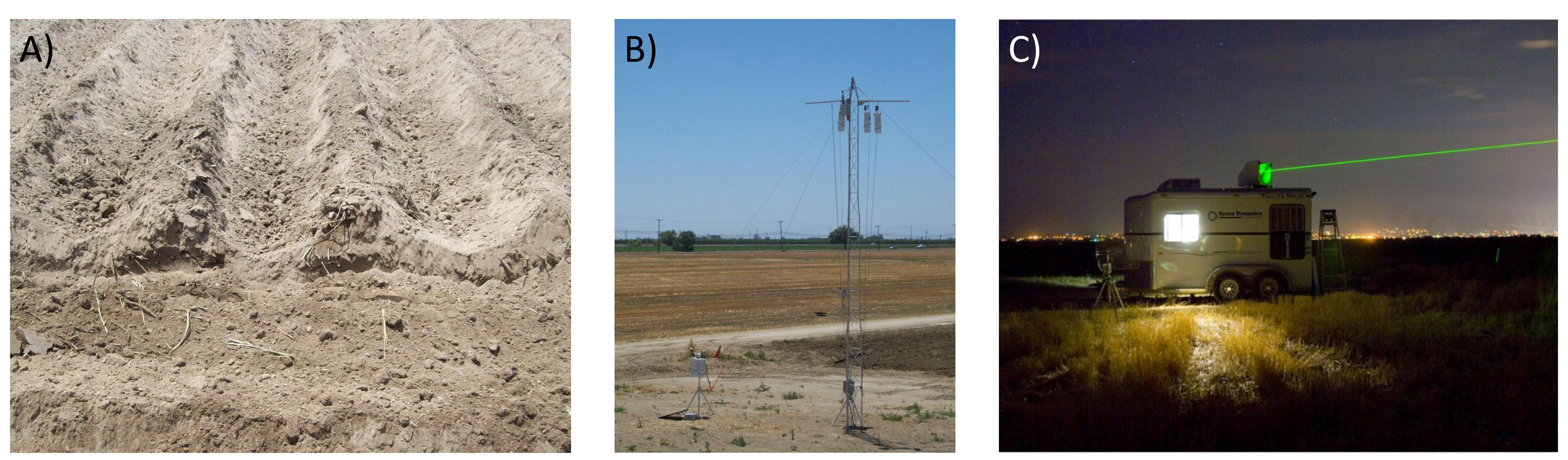

Figure 1. A) Field surface conditions immediately prior to the high wind event, B) point sensors deployed onsite, and C) the Aglite Lidar system.

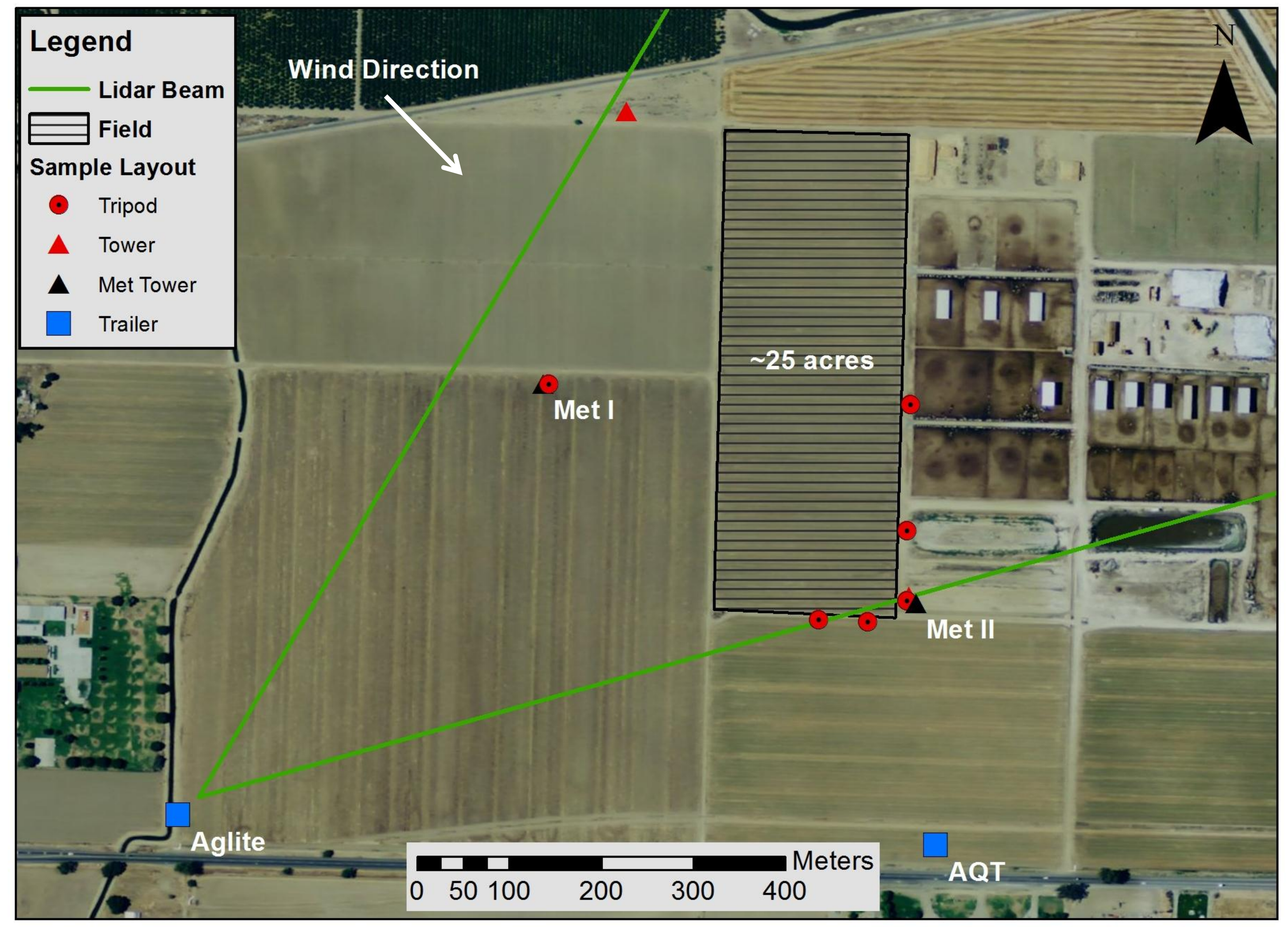

Figure 2. Sampling layout around the field showing locations of PM sensors on tripods and towers, meteorological towers, sample trailers, and Lidar vertical scanning planes.

Methodology (continued)

- Emission Rate (ER) Calculations
  - Process-produced concentration: $C_{diff} = C_{downwind} - C_{upwind}$
  - Inverse modeling with mean OPC PM data and AERMOD
    - Modeling: known ER used to predict concentrations
    - Inverse modeling: initial ER adjusted to find best fit to C_{diff}
  - Vertical flux method with mean OPC PM data
    - $F_v = \frac{k u_* (C_1 - C_2)}{\ln(\frac{z_2}{z_1})}$
    - Inputs: C_{diff} at two heights (z_1, z_2), friction velocity (u_*)
  - Mass balance applied to Lidar PM data
    - $ER = \frac{\sum(C_{diff,z} * wind_z)}{A_{vert.\,plane}}$

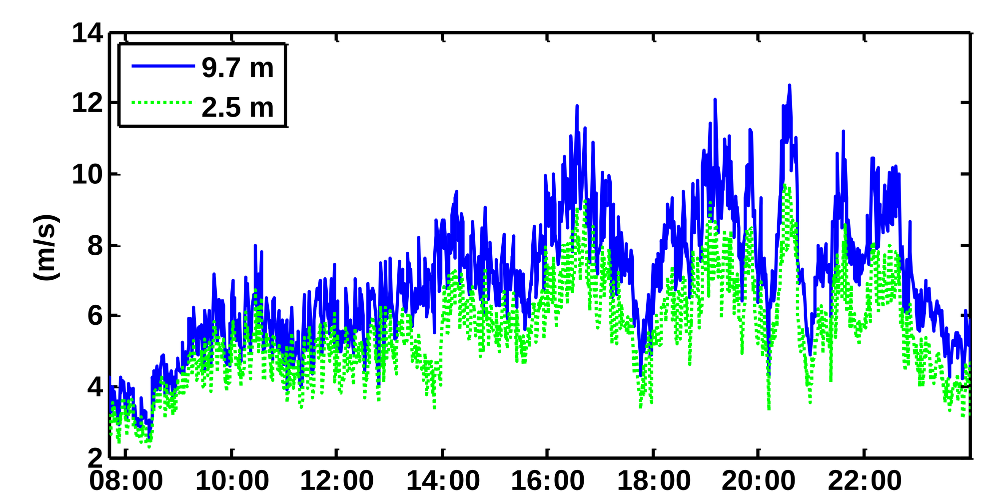

Figure 4. Wind speed measured onsite on May 20, 2008.

Results

- Meteorology
  - Wind direction: 316° ± 8°
  - Wind speed: Fig. 4
- OPC Measurements
  - Large sporadic downwind PM spikes (see Fig. 5)
  - Differences in PM with height (see Fig. 5)
  - PSDs have extremely large particle counts (see Fig. 6)

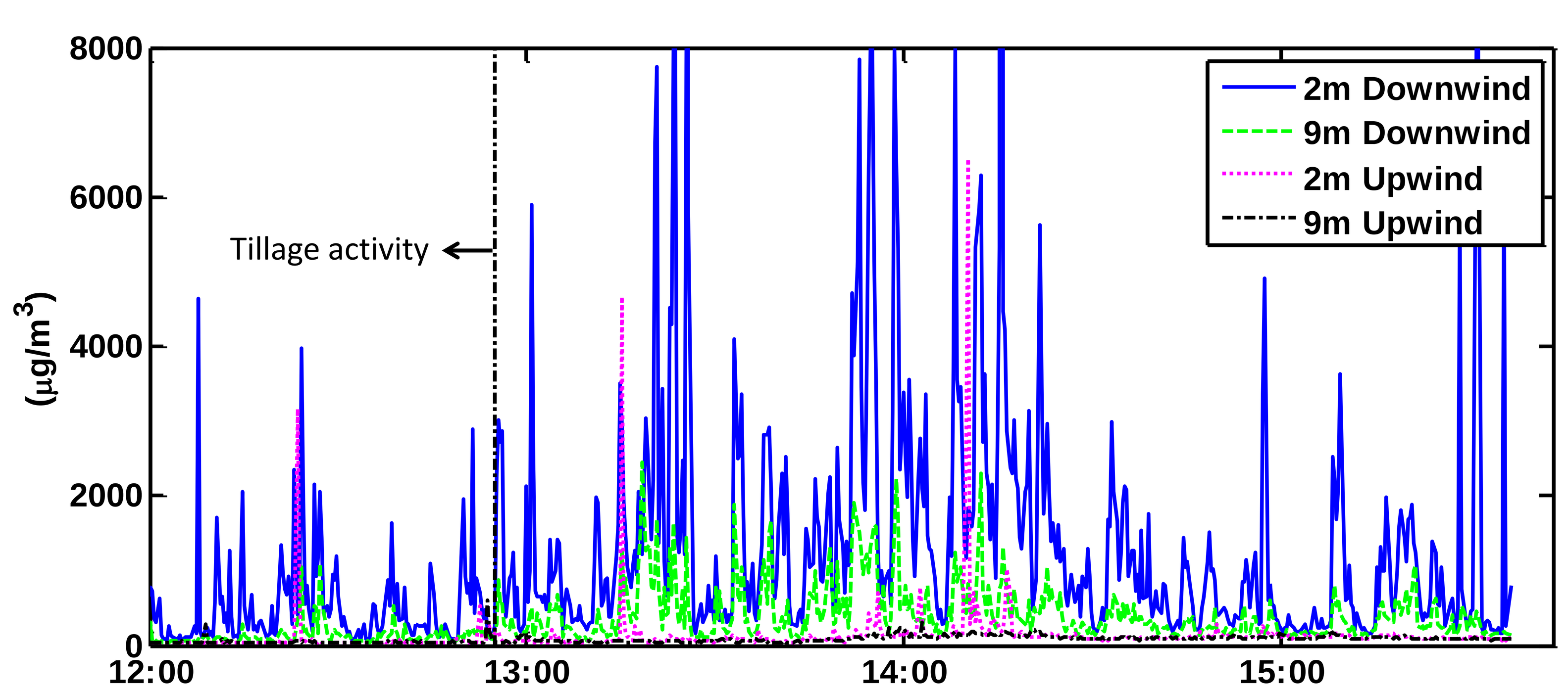

Figure 5. Time series of OPC PM_{10} data.

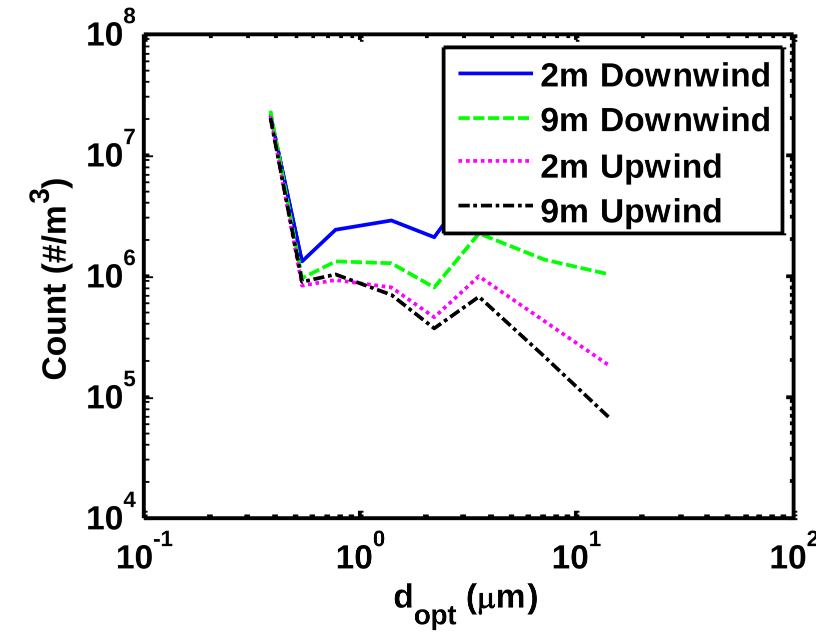

Figure 6. Mean PSDs measured from 13:00-15:00.

Results (continued)

- Lidar Measurements
  - Stare mode at ~10 m on downwind edge saw multiple plumes of varying sizes and strengths (see Fig. 7)
  - Horizontal and vertical scans captured plumes (see Fig. 8)
- Emissions Calculations
  - $PM_{2.5}$, PM_{10}, and TSP values estimated (see Table 1)
  - Lidar values comparatively very low

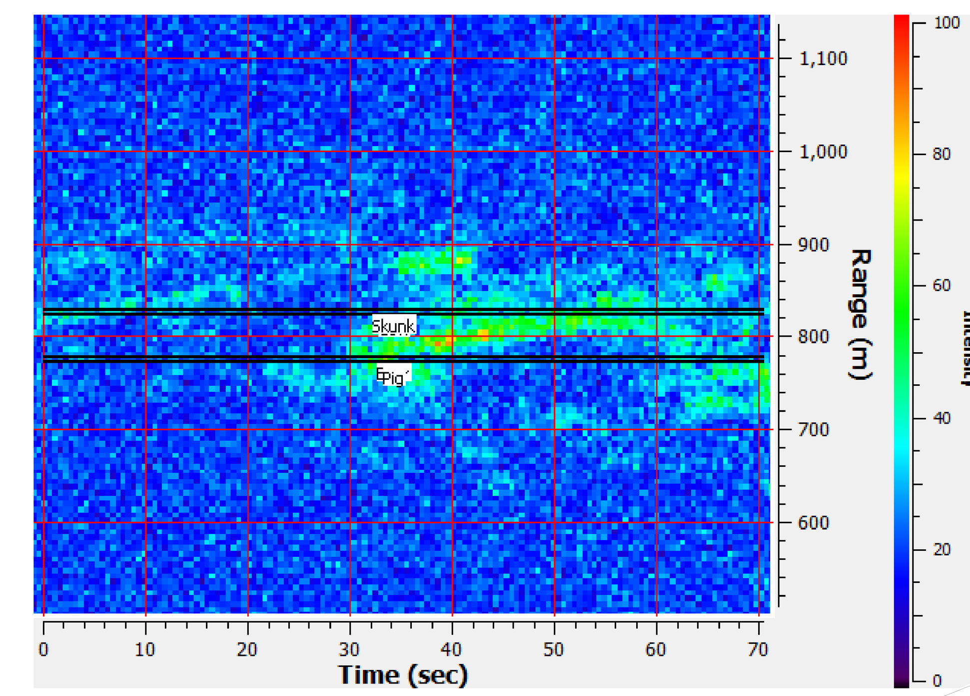

Figure 7. Wind-blown dust plumes detected by Aglite with beam stationary at ~10 m agl on downwind edge. Black solid lines represent ranges of OPCs.

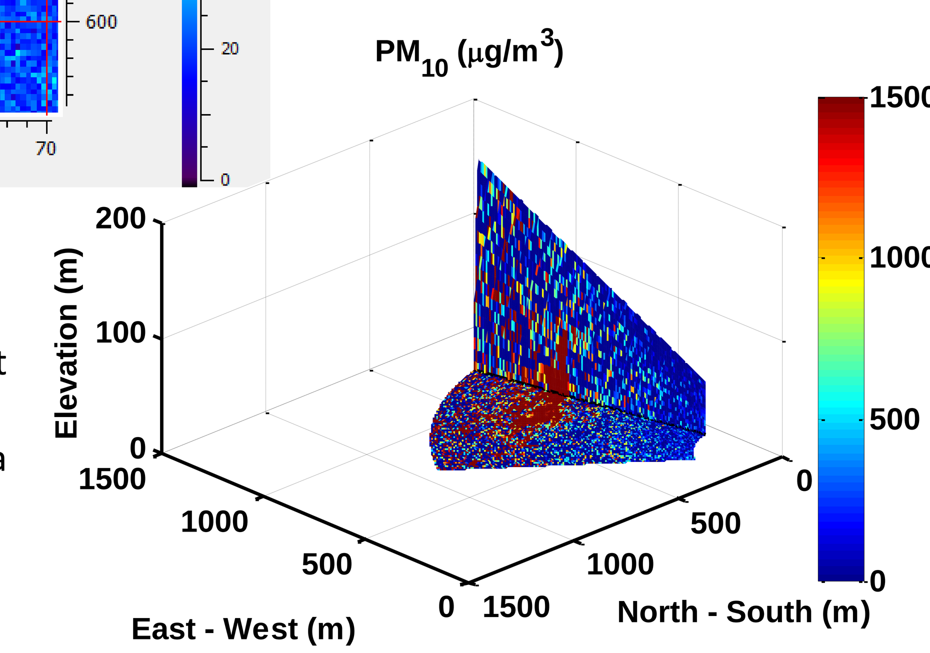

Figure 8. Example wind-blown dust plume detected by Aglite during a horizontal scan over the field and a vertical downwind scan.

Table 1. Estimated emission rates from the observed period of the wind erosion event.

Method	Time	n (OPC - # samplers, Lidar - # scans)	ERs (µg/s-m²)		
			$PM_{2.5}$	PM_{10}	TSP
Inverse modeling (OPC)	13:00-15:00	3	6.1	268.7	1,488.9
Vertical flux (OPC)	13:00-15:00	2	3.9	174.2	872.0
Mass balance (Lidar)	12:50-13:50	39	0.005 ± 0.006	0.137 ± 0.169	0.645 ± 0.801

Conclusions

- OPCs and Lidar successfully measured PM during a wind-blown dust event
- PM levels significantly decreased from 2m to 9 m
- Lidar measured plumes of varying size, location, and duration up to 50 m high
- $PM_{2.5}$, PM_{10}, and TSP ERs were estimated from 1-2 hours of measurements
- PM_{10} ERs from inverse modeling and vertical flux methods are similar to other values found in literature
- Lidar could not measure below ~10 m due to safety concerns, which may partially explain the Lidar-derived ERs being 10^3 lower than other two methods

Acknowledgments

- Cooperating producers and industry representatives
- Funding for instrumentation, data collection, and analysis: USDA ARS Cooperative Agreement #58-3625-4-121
- Field/support personnel